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EVALUATION OF AN OXYGEN CONCENTRATOR FOR USE AT HIGH ALTITUDE

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Supplying medical oxygen at high altitude sites is a major logistical problem. Oxygen concentrators based on molecular sieve technology provide an almost inexhaustible source of medical grade oxygen at a relatively low cost. However, data on the functional characteristics of O2concentrators at high altitudes are minimal.

Our objective was to determine the effectiveness of the oxygen concentrator at moderate and high altitudes. The study measured the maximum sustained O2 flow rate, O2 concentration [O2] and internal temperature (Ti) of the O2 concentrator for up to 8 hours at altitudes ranging from SL to 18,000 ft in a hypobaric chamber maintained at 20°C and 40% relative humidity.

At SL through 18,000', the O2 concentrator provided an [O2] of 95.3% $\pm$ 0.1% at a steady-state flow rate of 4.5 LPM $\pm$ 0.1 LPM, with Ti of 50.6°C $\pm$ 1.1°C. At each time interval over the 8 h period, the values for flow and [O2] did not fluctuate significantly. However, Ti increased slightly and steadily (~4°C rise) over the first 2 hours before stabilizing. The consistent pattern observed at each altitude was a low [O2] at the lowest and highest flow rates, with the highest [O2] producing middle range of flow rates. We conclude that from sea level to 18,000', molecular sieve based O2 concentrators are capable of providing medical grade supplemental O2 for at least 8 hours.

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BACKGROUND

Controlled oxygen therapy was developed and used to minimize respiratory problems in people with lung disease for many years. The standard oxygen delivery method is compressed oxygen in gas bottles. In the last decade, commercial oxygen concentrators have been used to alleviate respiratory problems in people with lung disease. Since well-controlled studies of O_2 concentrators has not been tested above 6000 feet, we evaluated one commercial device (Air Sep O_2 Con) to determine the effectiveness of this device to deliver 4-5 LPM of 95% or greater oxygen at sea level and at several altitudes for up to 8 hours. The successful test of the O_2 concentrator would reduce logistical support to ship and store O_2 cylinders for high altitude operations.

EXECUTIVE SUMMARY

Supplying medical oxygen at high altitude sites is a major logistical problem. Oxygen concentrators based on molecular sieve technology provide an almost inexhaustible source of medical grade oxygen at a relatively low cost. However, data on the functional characteristics of O_2 concentrators at high altitudes are minimal.

Our objective was to determine the effectiveness of the oxygen concentrator at moderate and high altitudes. The study measured the maximum sustained O_2 flow rate, O_2 concentration [O_2] and internal temperature (T_i) of the O_2 concentrator for up to 8 hours at altitudes ranging from SL to 18,000 ft in the USARIEM hypobaric chamber maintained at 20°C and 40% relative humidity.

At SL through 18,000 ft, the O_2 concentrator provided an [O_2] of 95.3% ± 0.1% at a steady-state flow rate of 4.5 LPM ± 0.1 LPM, with T_i of 50.6°C ± 1.1°C. At each time interval over the 8-h period, the values for flow and [O_2] did not fluctuate significantly. However, T_i increased slightly and steadily (~4°C rise) over the first 2 hours before stabilizing. The consistent pattern observed at each altitude was a low [O_2] at the lowest and highest flow rates, with the highest [O_2] producing middle range of flow rates. We conclude that from sea level to 18,000 ft, molecular sieve based O_2 concentrators are capable of providing medical grade supplemental O_2 for at least 8 hours.

INTRODUCTION

The concentration of oxygen (O_2) at SL is about 21% with a standard barometric pressure (P_B) of 760mm Hg. As altitude increases, the [O_2] remains the same, but the P_B decreases causing a reduction in the partial pressure of O_2 and consequently a reduction in the amount of O_2 that diffuses into the arterial blood. The decrease in the arterial O_2 content can result in hypoxia-induced symptoms (3,5,7,8,11). Recovery from the effects of acute hypoxemia is accomplished by the administration of supplemental O_2 or descent to lower altitudes (2,6,9,10,12).

The current method of supplying medical O_2 at remote high altitude sites is by high-pressure O_2 tanks. To support research studies at USARIEM Pikes Peak Laboratory, O_2 is shipped in large pressurized cylinders creating a potentially hazardous situation. A single pressurized H size O_2 cylinder weighs 125 pounds when it is full, and at 220 cu ft (6,200 liters) capacity, would last less than 1 day at a flow rate of 4 LPM. The cost of 220 cu ft is ~$25.00 per tank plus a daily demurrage charge of ~$1.00 per tank. The delivery schedule usually requires a greater number of cylinders to be purchased to insure O_2 is always available for testing and emergency purposes at this laboratory.

An alternative oxygen O_2 source is the O_2 concentrator. The O_2 concentrator produces a high [O_2] (~95% O_2 in the output gas mixture) by extracting nitrogen from the air utilizing a molecular sieve system. A sieving or screening action separates the smaller nitrogen molecules from the larger O_2 molecules. Nitrogen molecules penetrate a network of uniform pores in the adsorbent sieve material (i.e., aluminum silicate or synthetic zeolite) and are adsorbed by ion exchange on the interior surfaces of the pores. The larger O_2 molecules do not penetrate the pores and are redirected from the sieve to an internal mixing tank, which can contain up to 95% pure O_2. The O_2 can then be withdrawn from the mixing tank at a flow rate up to 5 LPM at SL.

Oxygen concentrators are considered regenerative systems. The molecular sieve method consists of a two-part cycle; a high-pressure intake phase and a depressurizing exhaust phase. Initially, room air is drawn into the concentrator where it passes through a series of filters that remove dust, bacteria, and other particulate matter. In the first phase, a compressor delivers the air into one of the two cylinders, and nitrogen is adsorbed producing concentrated O_2. In the second phase, nitrogen is de-sorbed under an applied vacuum and exhausted into the atmosphere. A typical O_2 concentrator includes two molecular sieve cylinders. The alternating phase function of each cylinder is to provide continuous O_2 delivery.

AirSep Corporation distributes an FDA approved (registered at the American National Standards Institute: Oxygen Concentrators:1981, ANSI Z-79.13) O_2 concentrator for human use at elevations as high as Denver, CO (5,300 ft, P_B = 625 mm Hg). Short duration tests conducted by AirSep Corp. (1, personal communication) show that a unit will deliver about 3.3 LPM (STPD) of 90% [O_2] at an altitude of (13,000 ft, P_B = 462 mm Hg. However, well-controlled tests of the AirSep concentrator in which flow and O_2 concentration were measured at altitudes above 6000 ft have not been published in the open literature (1,6,9).

The objective of this study was to measure the maximum flow rate sustainable for 8 hours at SL, at moderate to very high altitudes (2,000-18,000 ft, in 2,000 ft increments). In addition, the outflow gas [O_2], flow rate and internal temperature (T_i) were measured to assess gas quality and quantity for breathing.

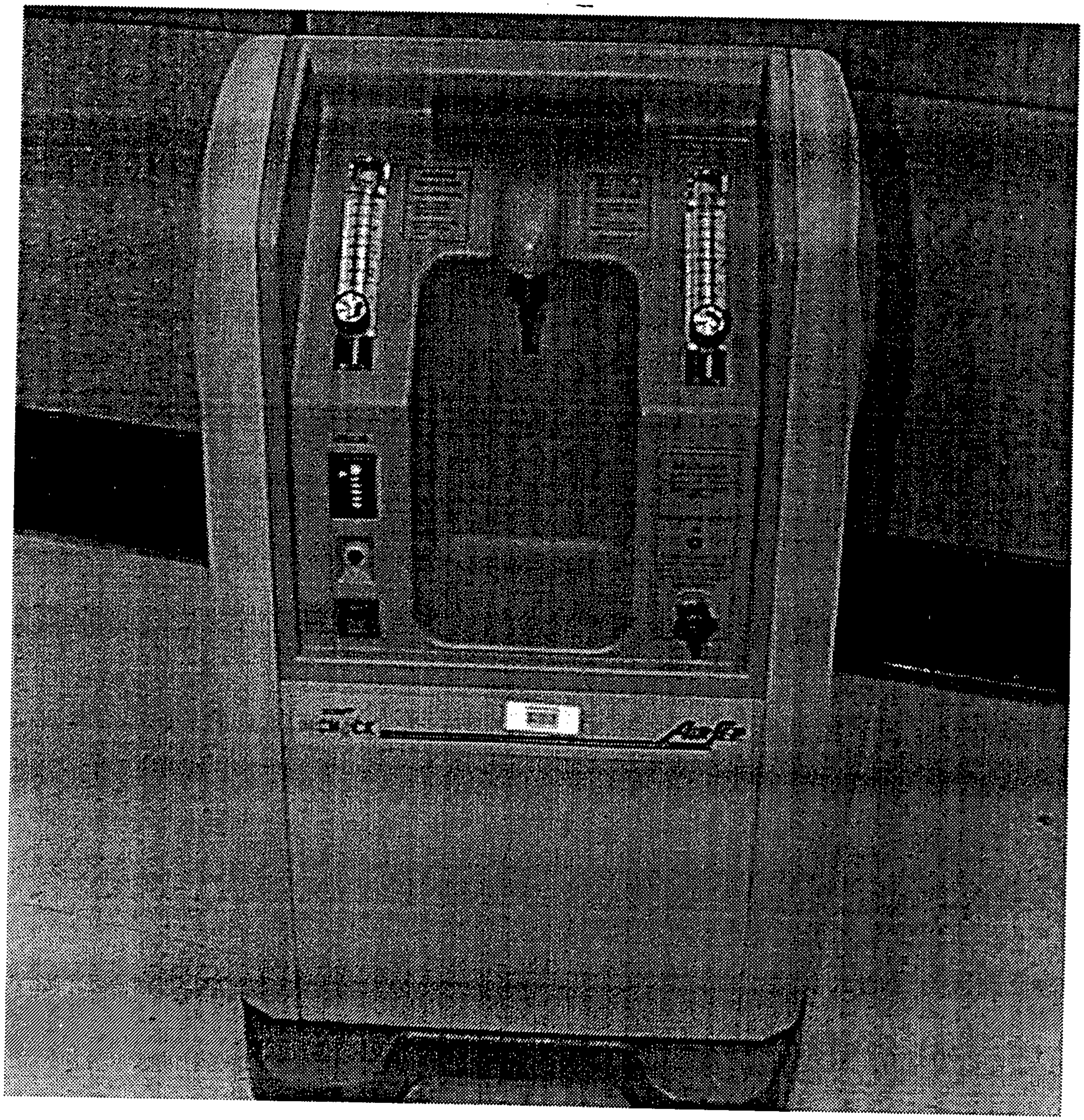
METHODS

DESIGN AND EXPERIMENTAL PROCEDURES

The effectiveness of the O_2 concentrator (AirSep, Model Newlife, Figure 1) at high altitude was evaluated by a series of tests which were performed at nine altitudes: SL (760 mmHg), 4,000 ft (656 mmHg), 6,000 ft (609 mmHg), 8,000 ft (564 mmHg), 10,000 ft (522 mmHg), 12,000 ft (483 mmHg), 14,000 ft (446 mmHg), 16,000 ft (422 mmHg), and 18,000 ft (380 mmHg). At each altitude, testing was maintained for at least 8 hours. Chamber environmental conditions were maintained at 20°C and 40% relative humidity.

During each test, the AirSep unit's outflow gas [O_2] (% O_2; fuel-cell analyzer, S-

FIGURE 1



AirSep, Model Newlife, Oxygen Concentrator

3A, Ametek, Sunnyvale, CA), flow rate in liters/minute (#470304A, flow transducer, Hewlett Packard, Lexington, MA) and T_i (YSI-Mdl-49TA, Yellow Springs Inst., Yellow Springs, Ohio) were continuously measured and recorded on a PC-based data acquisition system (AT-CODAS, DATAQ Instrument, Inc., Akron, OH) This is depicted in Figure 2.

STUDY DESIGN

Two tests were performed. First, at each altitude the maximal sustainable flow rate capable of delivering 95% [O_2] for 8 h was determined. (The Food and Drug Administration requirement for medical grade oxygen is 95% or greater [O_2], 10). The first series of tests (highest flow at which 95% O_2 was recorded) were conducted twice at each altitude on separate days for confirmation of those results. Second, in a series of tests, at SL, 12,000, 14,000 and 18,000 feet, O_2 flow rate was adjusted between 1-6 LPM for 10 minute intervals, while [O_2] and instrument T_i were recorded during the last minute.

RESULTS AND DISCUSSION

Figure 3 illustrates the O_2 flow rate, [O_2] and T_i over each 8-hour test period. Generally, all variables were stable over the duration of the tests. However, temperature increased slightly and steadily (~4°C rise) over the first 2 hours before stabilizing.

The mean ±SD for SL through 18,000' intervals for the three measured variables (flow-LPM, oxygen-%, and temperature °C) over each 8 hour test period are given in Table 1. The flow-rate averaged 4.5 LPM ± 0.2 LPM for baseline (SL) through 18,000'; [O_2] averaged 95.3% ± 0.2% for baseline (SL) through 18,000' (Table 1), and the average T_i (°C) was 51.9°C ± 3.6°C for baseline (SL) through 18,000'.

Figure 4 illustrates the effect of incremental changes in the O_2 concentrators' flow meter settings (1-6 LPM) on O_2 flow and [O_2] delivered at selected altitudes. The pattern observed at each altitude was a low [O_2] at the lowest and highest flow rates,

Figure 2
Schematic of Study System Design

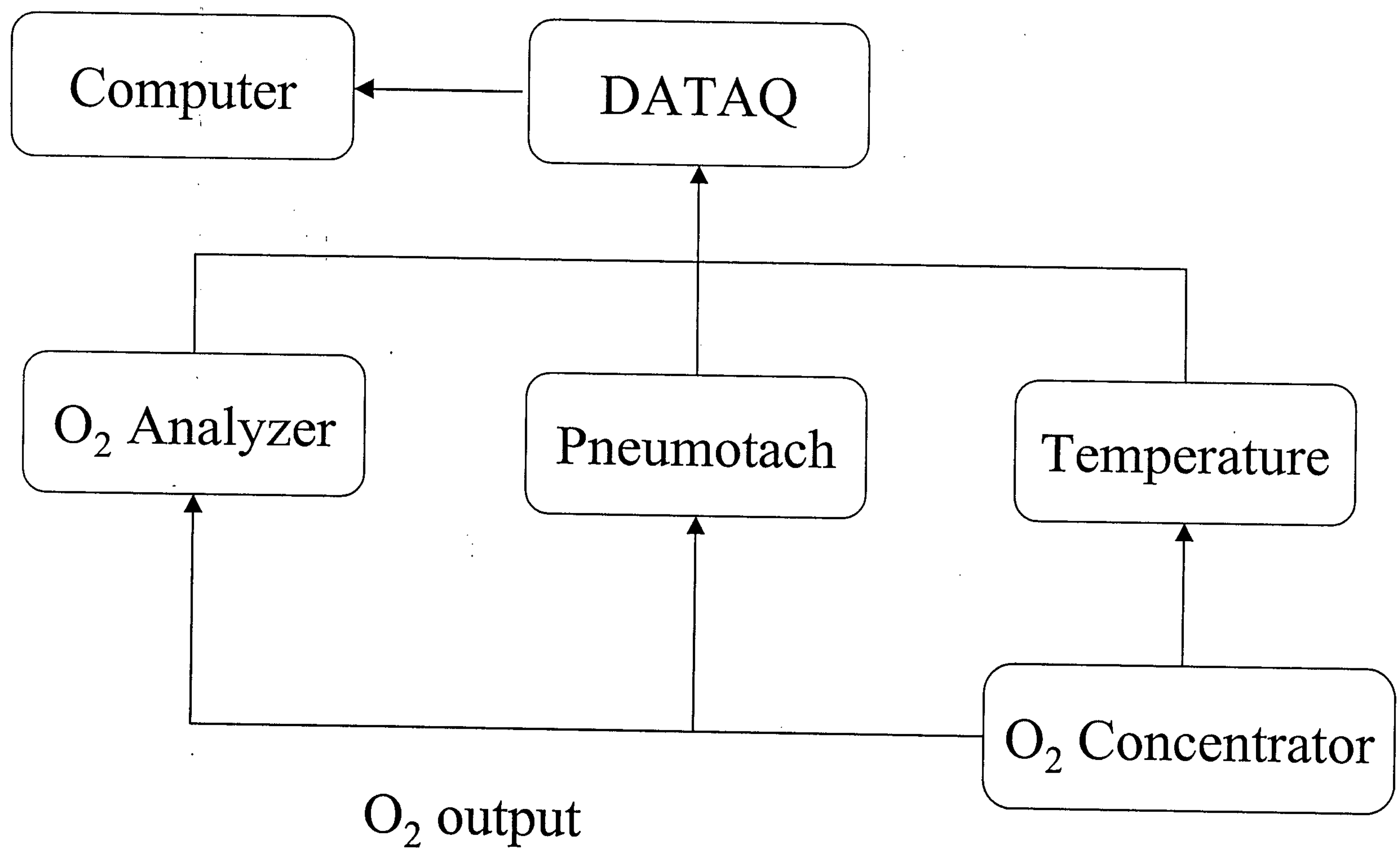
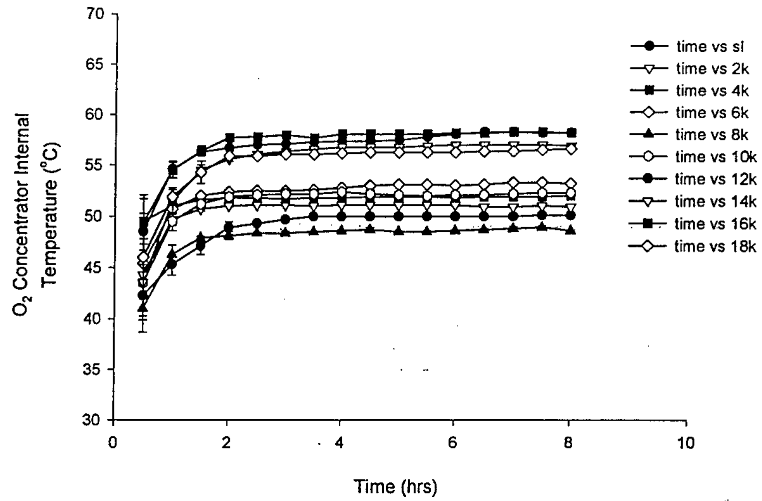
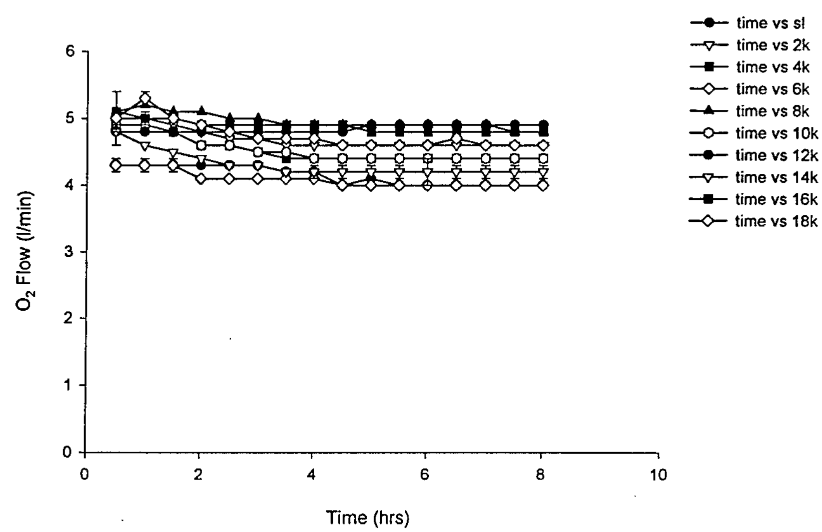


Figure 3
Eigth (8) hour averages for measured study parameters





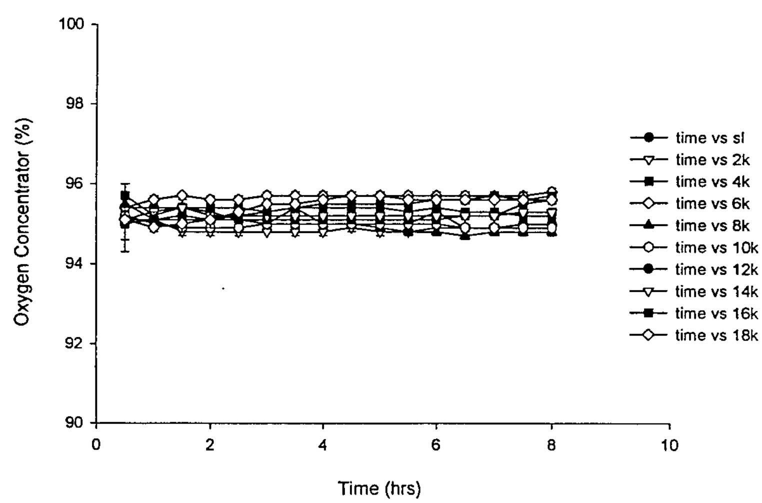
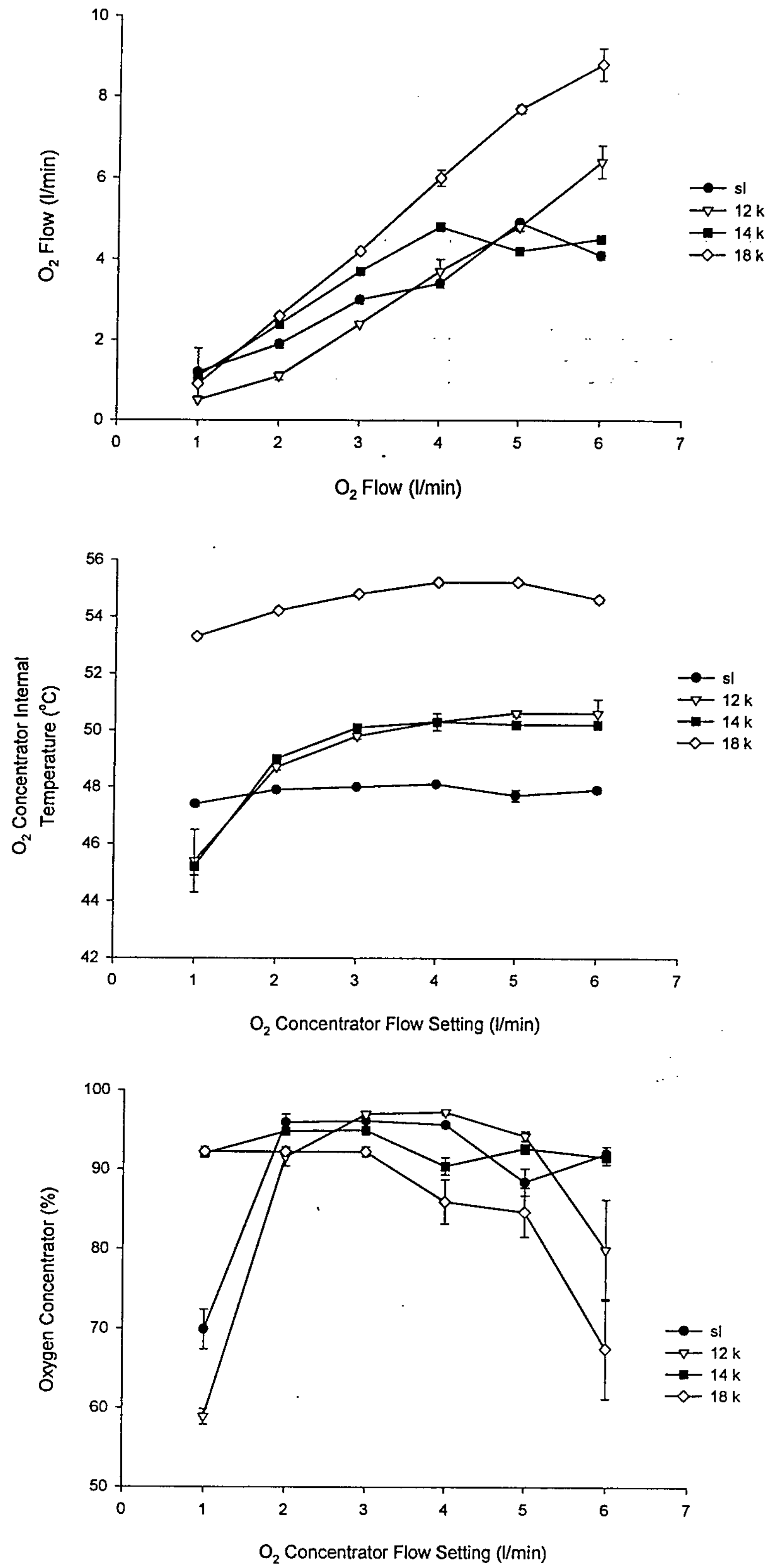


Table 1

Thirty minute (30') averages of the O_2 concentrator operational parameter over 8 hours test period from Sea Level thru 18,000 feet

Altitude	Flow (l/min)	O_2 (%)	Temperature (°C)
SL	4.3±0.0	95.3±0.2	58.4±0.5
2000	4.7±0.1	94.9±0.1	47.7±1.1
4000	4.4±0.3	95.2±0.1	51.3±1.6
6000	4.2±0.1	95.6±0.1	50.0±1.4
8000	5.0±0.1	95.4±0.2	49.1±1.3
10000	4.5±0.2	95.7±0.2	49.2±1.6
12000	4.5±0.1	95.4±0.2	55.3±1.9
14000	4.4±0.3	95.1±0.2	56.2±2.4
16000	4.9±0.1	95.4±0.3	57.2±2.4
18000	4.6±2.7	95.4±0.3	54.9±3.0

Figure 4
One (1) minute average from the end of ten (10) minute test period at selected altitudes.



with the greatest [O_2] produced in the middle range of flow rates (2.5 LPM).

Figure 5 is an illustration of the effect of increasing altitude on the relationship between the O_2 concentrators' flow rate setting and actual flow rate produced. The actual O_2 flow rate increased with increasing altitude.

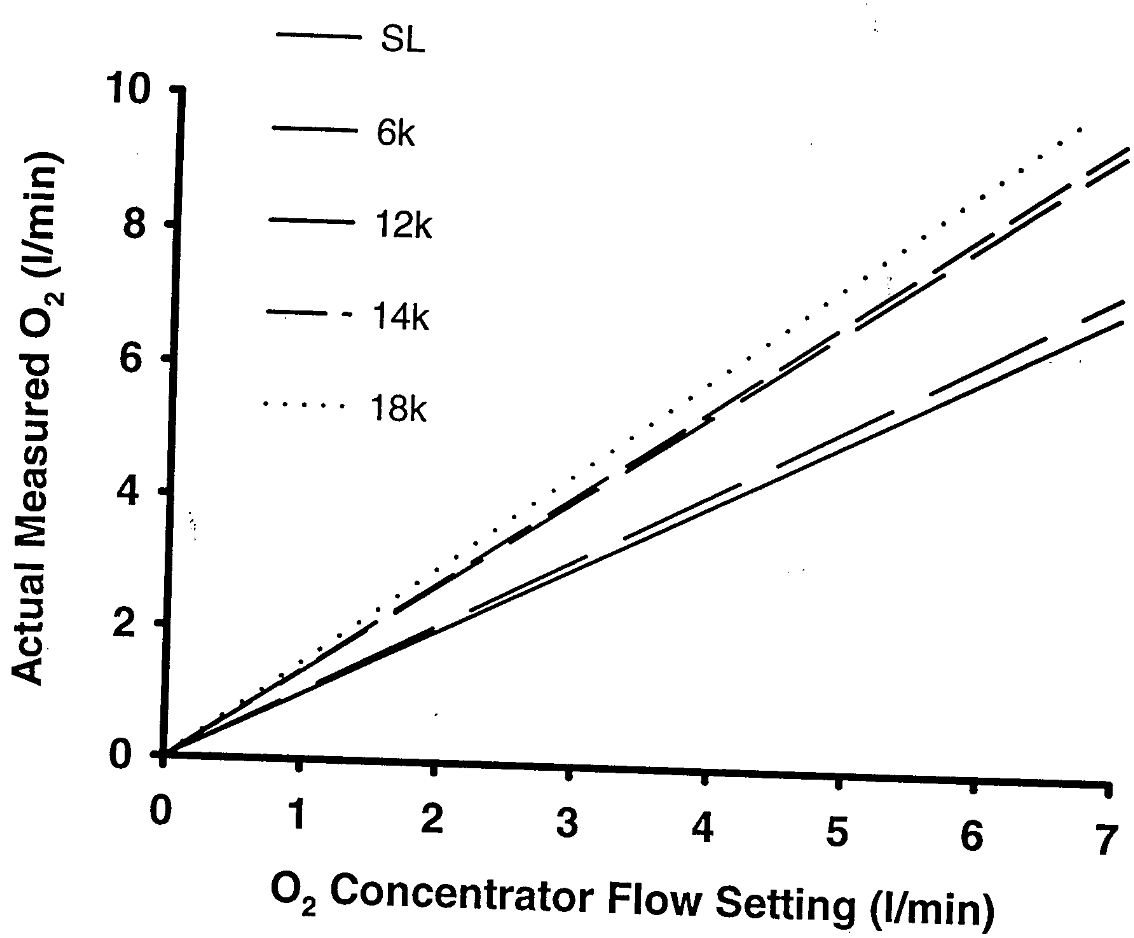
An average person would require one bottle (H-size, 220 cu ft, 125 pounds) per day or seven per week to sustain a flow rate of 4.5 LPM to either work at altitude or relieve altitude-related medical problems. The size oxygen vessel typically used is an E-size cylinder, which can supply 32 cu ft per cylinder and would require seven bottles per day or 49 per week. The cost can vary from $25.00 per H-size to $13.00 per E-size of O_2. In addition, there usually is a delivery charge for small volume users and a demurrage charge of $0.75 to $1.30 per cylinder per day. The typical energy use to deliver 5 LPM of O_2 with an O_2 concentrator is 350 watts of power (1). By comparison, the electrical energy cost (in Northeast U.S. area) for providing equivalent supply (5 LPM) of O_2 by an O_2 concentrator could range from ($24.00 to $31.00/month), with an initial acquisition cost of $800 to $1,000 depending upon options selected (1). A typical O_2 concentrator would become more cost-effective than cylinder supplied O_2 gas after 100 hours of operation.

CONCLUSIONS

From sea level to 18,000' the O_2 concentrator provided medical grade (95% O_2 or greater) at a maximal flow rate of about 4.5 LPM. Under these operating conditions the concentrator was capable of sustaining this level of oxygen delivery for at least 8 hours. It is recommended that the O_2 concentrator provided the bulk of the medical oxygen requirements for studies conducted at Pikes Peak Laboratory. The bottled O_2 tanks should be used only when electrical power is interrupted during these operations.

FIGURE 5

Linear regression illustrating relationship of actual O_2 concentrator flow at selected altitudes



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